

7.0 POLLUTION PREVENTION AND WASTEWATER TREATMENT TECHNOLOGIES

This section describes technologies that are used by the Transportation Equipment Cleaning Industry (TECI) to prevent the generation of wastewater pollutants or reduce the discharge of wastewater pollutants. Various combinations of these technologies were considered as the basis for the effluent limitations guidelines and standards for the industry (see Section 8.0).

Three major approaches are used by the TECI to improve effluent quality: (1) cleaning process technology changes and controls to prevent or reduce the generation of wastewater pollutants; (2) flow reduction technologies to decrease wastewater generation and increase pollutant concentrations, thereby improving the efficiency of treatment system pollutant removals; and (3) end-of-pipe wastewater treatment technologies to remove pollutants from transportation equipment cleaning (TEC) wastewater prior to discharge. These approaches are discussed in the following sections:

- Section 7.1: Pollution prevention controls used by the TECI;
- Section 7.2: Flow reduction technologies used by the TECI;
- Section 7.3: End-of-pipe wastewater treatment technologies used by the TECI; and
- Section 7.4: References used in this section.

7.1 Pollution Prevention Controls

EPA has defined pollution prevention as source reduction and other practices that reduce or eliminate pollution at the source. Source reduction includes any practices that reduce the amount of any hazardous substance or pollutant entering any waste stream or otherwise released into the environment, or any practice that reduces the hazards to public health and the environment associated with the release of such pollutants. Data gathered from the Detailed

Questionnaire shows that approximately 27% of TEC facilities currently practice water pollution prevention, and approximately 61% of TEC facilities currently practice heel pollution prevention. The principal pollution prevention controls applicable to the TECI are the use of dedicated tanks, heel reduction, and reduction in the amount or toxicity of chemical cleaning solutions. These pollution prevention controls are discussed in the following subsections.

7.1.1 Use of Dedicated Tanks

Tank cleanings are performed for two primary purposes: (1) to prevent contamination of materials from one cargo shipment to the next and (2) to facilitate inspection and repair. Certain segments of the TECI, such as shippers and carriers, frequently use tanks dedicated to hauling a single cargo (e.g., gasoline) that require no, or less frequent, cleaning between loads. Most TEC facilities cannot implement the use of dedicated tanks since it is only the shipper or carrier offering the container for cleaning that can exercise the use of dedicated tanks. Benefits from the use of dedicated tanks include:

- Reduced costs as a result of fewer tank cleanings;
- Reduced waste management and disposal costs because heel removal and disposal are not required;
- Elimination of the generation of tank cleaning wastewater and associated pollutant discharges; and
- Reduced tank cleaning wastewater treatment costs and/or sewerage fees.

Impediments to the use of dedicated tanks include:

- Product purity concerns that necessitate cleaning to prevent contamination of subsequent cargos; and
- Financial loss due to inefficient equipment allocation (i.e., dedicated tanks are precluded from use to transport other cargos).

7.1.2 Heel Reduction

Heel is the residual cargo remaining in a tank or container following unloading, delivery, or discharge of the transported cargo and is the primary source of pollutants in TEC wastewater. Measures may be taken before, during, and after the tank cleaning process to reduce the amount of heel that enters the wastewater stream. These heel reduction measures are described later in this section.

Excessive heels are also an important economic consideration for the TECI. For example, many cargos are valuable, and any product waste represents a significant loss. In addition, profits from transporting product and/or cleaning tanks can be offset by large heel disposal costs. As a result, the TECI has a strong economic incentive to minimize heels.

Heel generation occurs during the unloading of a tank. Since tank unloading frequently does not occur at the TEC facility, the carrier, shipper, or consignee may have a more direct control over heel generation than the TEC facility that will ultimately clean the tank and dispose the heel. TEC facilities can develop a heel minimization program that identifies the sources of heels and institutes practices that discourage heel generation by carriers, shippers, and consignees.

Tank cleaning facility personnel cite education of, and communication among, the carrier, shipper, and consignee as critical components of an effective heel minimization program. Carriers, shippers, and consignees may not be aware of the problems associated with excess heels and may not understand how heel minimization best serves their interests. An effective heel minimization program is best implemented as a partnership among the carrier, shipper, consignee, and tank cleaning facility and may include the following components:

- Drivers should be trained to identify excess heels;
- Drivers should perform pre- and post-trip inspections and discuss with the consignee methods for reducing excess heels;

- If excess heel is not resolved with the consignee, the driver should report excess heel to the driver's manager. Drivers should document heel issues or problems including offloading conditions which may have caused excess heel;
- Carriers should provide data to the shipper on amounts of heels;
- Facilities should consider heel management options other than disposal, such as redelivering the product to the consignee or drumming the heel and returning it to the shipper or consignee;
- Facilities should evaluate any company policies that punish or fine drivers for excess heel to ensure that the policies do not encourage illicit heel disposal;
- Drivers should consider inviting shippers to accompany them during product delivery to gain a first hand perspective and understanding of factors impacting heel volumes;
- Facilities may refuse or reject tanks for cleaning if excessive heel is present;
- Facilities may charge an extra fee per amount of heel received as an incentive to minimize heel;
- Facilities may refuse to accept particular cargos for one or more of the following reasons: federal, state, local, or other environmental permit limitations; safety considerations; facility cleaning capabilities; and/or facility wastewater treatment system capabilities;
- The heel minimization programs, pollution prevention plans, and tank cleaning standard operational procedures should be written and carefully followed by all personnel involved in heel generation and management; and
- Personnel should undergo ongoing training so that changes in the heel minimization program and new procedures and policies will not be overlooked.

Implementation of an effective heel program can provide significant environmental and economic benefits. In order to achieve the environmental and economic benefits associated with heel reduction, TEC facilities should employ appropriate heel reduction techniques in

addition to implementing an effective heel minimization program. Heel reduction techniques are discussed in the following paragraphs.

During tank cleaning operations, some TEC facilities incorporate procedures to remove as much heel as possible so that it can be segregated from the tank cleaning wastewater. One procedure, used particularly for tanks that last transported petroleum products, is to steam the inside of the tank to lower the viscosity of the heel to facilitate draining. The steamed tank is then drained to remove additional heel. Similarly, tanks, drains, and fittings may be preheated with steam or hot water to facilitate product draining. Another procedure applicable to certain cargos is for tank cleaning personnel to enter the tank and manually squeegee heel toward the valve openings. (Physically entering a tank may not be advisable in many circumstances. Personnel must be trained in health and safety procedures and a confined space entry permit may be required.)

A third procedure is to perform a hot or cold water prerinse (subsequent to primary heel removal via draining) to enhance heel removal. This procedure uses a short burst of water (e.g. 5 to 10 seconds) to remove heel from the tank interior. The prerinse wastewater (containing residual heel) is drained and managed separately from tank cleaning wastewater. Note that some facilities perform tank prerinses solely as a means to increase the useful life of tank cleaning solutions (by minimizing solution contamination with heel) rather than as a TEC wastewater pollution prevention procedure. These facilities do not manage the prerinse wastewater separately from the other tank interior cleaning wastewaters.

After tank cleaning is complete, facilities employ various heel management practices (such as reuse, recycle, or disposal) so that heel is managed separately from tank interior cleaning wastewater. Reuse and recycle may be accomplished by any one of several methods. One method is to return the heel to the consignee. Some heels can be reused at the TEC facility. For example, fuel and fuel oil heels can be used in TEC facilities' on-site boilers or in their own transportation equipment. Heels comprised of soaps, detergents, solvents, acids, or alkalis may be reused by TEC facilities for tank cleaning, neutralization, or wastewater treatment. Many food

grade heels can be recycled as animal feed. Some heels, such as fertilizers, can be segregated, stored, and sold as product.

Heel that cannot be recycled or reused can be managed separately from tank interior cleaning wastewater. The most common method of heel disposal is land disposal. This practice is most often performed with petroleum and coal product heels and dry-bulk cargo heels. Heels may also be hauled to a privately owned treatment works, federally owned treatment works, centralized waste treatment works, ballast water treatment facility, or hazardous waste treatment, storage, and disposal facility, all of which are frequently better equipped to treat these wastes.

7.1.3 Reduction in the Amount and Toxicity of Chemical Cleaning Solutions

Many cargo types require the use of chemical cleaning solutions in the tank cleaning process. In addition to the contaminants contained in the heel removed by chemical cleaning solutions, the chemicals used in the solutions may themselves be toxic. These chemical cleaning solutions are a significant source of pollutants in TEC wastewater. By reducing the amount and toxicity of chemical cleaning solutions used in the tank cleaning process, tank cleaning facilities can reduce the contribution of cleaning solutions to the total wastewater pollutant concentrations. These pollution prevention procedures include recirculating and reusing cleaning solutions, disposing cleaning solutions separately from tank interior cleaning wastewater, and using less toxic cleaning solutions. These measures are described further in the following paragraphs.

The majority of TEC facilities that discharge chemical cleaning solutions with their tank cleaning wastewater recycle and reuse the solutions at least once prior to discharge. Recycle and reuse is usually achieved through the use of automated cleaning systems or cleaning solution recirculation loops that allow reuse of the cleaning solutions until their efficacy diminishes below acceptable levels. This reduces the amount of additional chemical cleaning solution required for each tank cleaned; instead, smaller amounts of make-up solution are periodically added to replace

solution lost in the final rinse or to boost efficacy. As previously mentioned, a hot or cold water prerinse may also be used to extend the useful life of a chemical cleaning solution, thereby reducing the total amount of chemical cleaning solution needed for tank cleaning.

Another method of reducing the introduction of chemical cleaning solutions to the wastewater streams is to capture the spent solutions (both interior and exterior cleaning solutions) and dispose them off site at a treatment facility that is better equipped to treat these concentrated chemical wastes than on-site wastewater treatment systems. Off-site disposal can be combined with the recirculation and reuse of cleaning solutions (described above) to reduce the need for fresh cleaning solution and to minimize the amount of cleaning solutions that enter the facility wastewater treatment system.

Many facilities in the TECI substitute less toxic cleaning solutions, where appropriate, to reduce the amount of toxic pollutants that are introduced to the wastewater stream. Typically, presolve solutions are the most toxic chemical cleaning solutions and are least compatible with facility wastewater treatment systems. Presolve usually consists of diesel fuel, kerosene, or some other petroleum-based solvent and is used to clean hardened or caked-on products that are not easily removed by other cleaning processes. In many cases, presolve may be substituted by acidic or caustic solutions to which detergent “boosters” (e.g., glycol ethers or esters) are added to improve their effectiveness. At some facilities, chemical cleaning solutions may be eliminated by using steam cleaning or hot or cold water washes for water-soluble cargos or by extending the process time of cleaning steps that do not use toxic cleaning solutions.

As in the case of heel reduction, these methods to reduce the amount and toxicity of chemical cleaning solutions benefit from written cleaning process standard operating procedures and pollution prevention plans that are carefully followed by cleaning personnel. Facilities should also conduct ongoing training for cleaning personnel to insure that the procedures contained in these resources will be practiced at all times.

7.2 Flow Reduction Technologies

This section describes technologies that can reduce the volume of wastewater discharges from TEC facilities. Flow reduction offers the following benefits: (1) increased pollutant concentrations which increase the efficiency of the wastewater treatment system; (2) decreased wastewater treatment system equipment sizes, resulting in reduced treatment system capital and operating and maintenance costs; and (3) decreased water and energy usage. Data gathered from the Detailed Questionnaire show that approximately 45% of TEC facilities currently practice flow reduction/water conservation. Flow reduction technologies applicable to the TECI serve to reduce the amount of fresh water required for tank cleaning through cleaning process modifications and/or recycling and reusing process wastewaters in TEC or other operations. These flow reduction technologies are presented in the following subsections.

7.2.1 High-Pressure, Low-Volume Cleaning Equipment

The use of high-pressure, low-volume cleaning equipment is one of the most effective tools for reducing water use. The most common type of this equipment is spinner nozzles, which are nozzles designed to rotate around both vertical and horizontal axes to create an overlapping spray pattern that cleans the entire interior of the tank. Spinner nozzles are inserted through the main tank hatch and operated at pressures between 100 pounds per square inch (psi) and 600 psi to deliver hot or cold water rinses and a variety of cleaning solutions for tank cleaning final rinses. Spinners can be operated using pulsing pump technology where water is delivered in bursts of a few seconds, further reducing the volume of water. Washing with high-pressure, hand-held wands with stationary nozzles achieves the same result as washing with high pressure spinner nozzles but requires facility personnel to manually direct the wash solution across the interior surface of the tank.

7.2.2 Monitoring TEC Water Use

Cleaning personnel can monitor the amount of water required for tank cleaning so that the minimum amount of water is used to clean each specific tank and cargo type. One approach is to inspect each tank to determine the state and amount of residual cargo remaining and thereby determine the duration and amount of water required for cleaning. A more general approach is to have a predetermined water use and cleaning time for each tank type and cargo combination based on previous tank cleaning experience.

7.2.3 Equipment Monitoring Program

The implementation of an equipment monitoring program can significantly reduce fresh water requirements by eliminating water waste. Pumps, hoses, nozzles, water storage tanks, and cleaning solution tanks may develop leaks and require prompt attention by facility personnel. Preventative maintenance, periodic inspection, and prompt repair of leaks can help ensure that no unnecessary water waste occurs.

7.2.4 Cleaning Without Use of Water

Dry cleaning processes (i.e., cleaning processes that do not require water) are effective for removing some cargos, particularly dry-bulk goods and viscous liquids. Mechanical devices may be used to vibrate hoppers to improve heel removal. Some dry cleaning processes, particularly applicable to hopper or tank barges, include manual operations to shovel or sweep dry-bulk cargos, or mop or squeegee liquid cargos to remove as much residual material as possible. (Physically entering a tank may not be advisable in many circumstances. Personnel must be trained in health and safety procedures and a confined entry space entry permit may be required.) Depending on the effectiveness of these dry cleaning processes, the need for subsequent tank cleaning with water may be eliminated. At a minimum, these techniques will reduce the amount of water and cleaning solution required for tank cleaning.

7.2.5 Cascade Tank Cleaning

Facilities that primarily clean tanks used to transport the same cargos (e.g., petroleum facilities) often operate “cascading” tank cleaning processes. In these processes, the most contaminated TEC process wastewater is used for initial tank rinses, with initial tank rinse wastewater routed to disposal. Clean water, or relatively clean TEC process wastewater, is used for final tank rinses, with final tank rinse water reused as an initial tank rinse when cleaning subsequent tanks. Through this process, wash water is used at least twice prior to discharge or disposal.

7.2.6 Wastewater Recycle and Reuse

In addition to cascading tank cleaning processes, TEC facilities may incorporate other methods of water recycle and reuse to reduce or eliminate the need for fresh process water. Wastewater streams most commonly recycled and reused for TEC operations include tank interior cleaning wastewater, hydrotesting water, uncontaminated stormwater, and noncontact cooling water. If hydrotesting water, uncontaminated stormwater, and noncontact cooling water are segregated from tank interior cleaning wastewater, these wastewaters do not require extensive treatment prior to recycle and reuse.

Tank interior cleaning wastewater generated by cleaning tanks used to transport petroleum products can typically be reused as tank interior cleaning water after treatment by oil/water separation and activated carbon treatment. Wastewater generated by cleaning tanks that last transported chemical products generally requires more extensive treatment prior to reuse as source water in TEC operations. Final tank rinse water may also be used as cleaning solution make-up water.

Tank hydrotesting wastewater may be reused as future hydrotesting water by pumping to a storage tank between tests. Because hydrotesting usually requires that the entire

tank be filled (approximately 5,000 gallons for an intermediate sized tank truck), the reuse of hydrotest wastewater can save substantial volumes of fresh water.

7.3 End-of-Pipe Wastewater Treatment Technologies

End-of-pipe wastewater treatment includes physical, chemical, and biological processes that remove pollutants from TEC wastewater prior to discharge to a receiving stream or POTW. Many TEC facilities use pretreatment, primary treatment, biological treatment, and/or advanced treatment for end-of-pipe treatment of wastewater. [See Table C-6 of the Data Element Dictionary for the Detailed Questionnaire (1) for the specific technologies included within these technology classifications.] Typical end-of-pipe treatment currently used by the TECI includes pretreatment and primary treatment. TEC facilities that operate biological and/or advanced treatment units are commonly those that practice extensive water and wastewater recycle and reuse or discharge directly to U.S. surface waters.

The following subsections describe the major wastewater treatment technologies used by the TECI. Each subsection includes a general description of how the technology works and what types of pollutants the technology treats. The number of TEC facilities that use each treatment technology is presented in the following table. The numbers of facilities presented in this table have been adjusted using statistical scaling factors and therefore represent the entire industry rather than only the surveyed facilities. The following subsections describe each of these technologies in the order that they appear in the table.

Treatment Technology	Number of Facilities (% of Discharging Facilities) That Utilize the Treatment Technology
Gravity Settling	393 (57%)
pH Adjustment	303 (44%)
Equalization	289 (42%)
Oil/Water Separation	251 (36%)
Sludge Dewatering	195 (28%)
Dissolved Air Flotation	175 (25%)

Treatment Technology	Number of Facilities (% of Discharging Facilities) That Utilize the Treatment Technology
Coagulation/Flocculation	169 (24%)
Filtration	166 (24%)
Clarification	157 (23%)
Biological Oxidation	60 (9%)
Chemical Precipitation/Separation	43 (6%)
Grit Removal	30 (4%)
Chemical Oxidation	16 (2%)
Activated Carbon Adsorption	4 (<1%)
Membrane Filtration	1 (<1%)

7.3.1 Gravity Settling

Gravity settling, or sedimentation, removes suspended solids from TEC process wastewater by maintaining wastewater in a quiescent state so that contaminants can separate by density. Gravity settling is utilized by more than half of the TEC facilities (57%). During gravity settling, wastewater is typically collected in a tank or catch basin, where it is detained for a period of time, allowing solids with a specific gravity higher than water to settle to the bottom of the tank and solids with a specific gravity lower than water to float to the surface. The effectiveness of gravity separation depends upon the characteristics of the TEC wastewater and the length of time the wastewater is held in the treatment unit. Properly designed and operated gravity separation units are capable of achieving significant reductions of suspended solids and 5-day biochemical oxygen demand in many TEC wastewaters.

Some facilities add chemicals, such as lime or polymers, to aid in the settling of solids. The solids that settle out or float to the surface may be removed from the unit continuously using automatic scrapers or skimmers. Alternatively, the units may be periodically shut down and the solids removed manually.

7.3.2 pH Adjustment

Adjustment of pH is a process in which chemicals are added to a wastewater to make it acidic or basic or to neutralize acidic or basic wastewaters. Of the total TEC facilities, 44% utilize pH adjustment. A pH adjustment system normally consists of a small tank in which the wastewater pH is adjusted by mixing and chemical addition under the control of a pH meter. To adjust the pH of the wastewater, either caustic or acidic chemicals are added to the mixing tank. Because many treatment technologies used in the TECI are sensitive to pH fluctuations, pH adjustment may be required as part of an effective treatment system. Some treatment technologies require a high pH (e.g., chemical precipitation), while others require a neutral pH (e.g., biological oxidation). In addition, the pH of the final effluent from these technologies must often be adjusted prior to discharge to meet permit conditions for wastewater discharge.

7.3.3 Equalization

Equalization involves homogenizing variable wastewaters over time to control fluctuations in flow and pollutant characteristics, thereby reducing the size and cost and improving the efficiency of subsequent treatment units. Approximately 42% of TEC facilities incorporate equalization in their wastewater treatment processes. Equalization units include tanks which are often equipped with agitators (e.g., impeller mixers and air spargers) to mix the wastewater and to prevent solids from settling at the bottom of the unit. Chemicals may also be added to the equalization units to adjust pH, as necessary, for further treatment.

Equalization units can allow downstream treatment units to be sized and operated on a continuous-flow basis, because they can minimize the variation in the characteristics of untreated wastewaters. This reduces the probability of treatment system upsets and allows treatment systems to be optimized for a narrower range of influent wastewater characteristics. The amount of residence time required by an equalization unit to achieve optimum effects is dependent upon the specific characteristics and daily flow patterns of the wastewater.

7.3.4 Oil/Water Separation

Oil/water separation uses the difference in specific gravity between oil and water to remove free or floating oil from wastewater. More than one-third of TEC facilities (36%) use oil/water separation as a method of removing varying levels of oil and grease.

The most common mechanism for oil removal is an oil skimmer. Some skimming devices work by continuously contacting the oil with a material, such as a belt or rope, onto which the oil readily adheres. As the material passes through the floating oil layer, the oil coats the surface of the material. The oil-coated material then passes through a mechanism that scrapes the oil from the material into an oil collection unit. Another type of skimming device uses overflow and underflow baffles to skim the floating oil layer from the surface of the wastewater. An underflow baffle allows the oil layer to flow over into a trough for disposal or reuse while most of the water flows underneath the baffle. This is followed by an overflow baffle, which is set at a height relative to the first baffle such that only the oil-bearing portion will flow over the first baffle during normal operation.

A standard oil/water separator utilized by the TECI is an American Petroleum Institute (API) oil/water separator. A typical API oil/water separator is rectangular and constructed with surface skimmers for oil removal and a bottom sludge rake or sludge auger for solids removal. It is designed such that lighter floating matter rises and remains on the surface of the water until removed, while the liquid flows out continuously under partitions or through deep outlets. Figure 7-1 presents a diagram of an API oil/water separator.

Another common type of oil/water separator used by the TECI is a coalescing oil/water separator, which is used to remove oil droplets too finely dispersed for conventional gravity separation and skimming technology. These units are comprised of a series of corrugated and/or inclined plates or tubes arranged parallel to one another and transverse to the flow of water. The plates and tubes are often built of materials that attract oil away from the water, such as polypropylene, ceramic, or glass. As the oil droplets impinge on the surfaces of the plates or

tubes, they coalesce into a layer of oil that flows or is pumped from the unit. Figure 7-2 presents a diagram of a coalescing oil/water separator.

Due to the complex nature of TEC wastewater and the presence of detergents and high-pH chemicals, oils may form a stable emulsion which does not separate well in a gravity or coalescing separator. Stable emulsions require pH adjustment, the addition of chemicals, and/or heat to break the emulsion. The method most commonly used by the TECI to perform oil/water separation on stable emulsions is acid cracking. Acid cracking entails the addition of sulfuric or hydrochloric acid to the tank containing the oil mixture until the pH reaches 1 or 2. A coagulant may also be added during acid cracking to aid in oil/water separation. After the emulsion bond is broken, the free oil floats to the top of the tank where it is removed by a skimming device.

7.3.5 Sludge Dewatering

Sludge dewatering reduces sludge volume by decreasing its water content. Various methods of this particular process are employed by 28% of the TECI. Sludge dewatering may involve simple techniques such as the use of sludge drying beds, or it may be accomplished through more complicated mechanical techniques, including filter presses, rotary vacuum filters, and centrifuges. The decrease in sludge volume achieved through sludge dewatering substantially reduces the cost for sludge disposal and allows for easier sludge handling.

7.3.5.1 Sludge Drying Bed

The sludge drying bed process involves applying sludge to land, collecting the supernatant after solids settle, and allowing the sludge to dry. The sludge cake may then be scraped manually or by a front-end loader and dumped into a truck. Disadvantages to using a sludge drying bed are potential odor problems, large land area requirements, and the cost of labor to remove the dried cake. The main components of a sludge drying bed include watertight walls extending above the surface of the bed; an opening in the wall for entrance of a front-end loader to scrape up the sludge cake; drainage trenches filled with a coarse sand bed supported on a

gravel filter with a perforated pipe underdrain; paved areas on both sides of the trenches with a slope for gravity drainage; and a sludge inlet and supernatant draw-off (2). The supernatant collected from the sludge may be returned as influent to wastewater treatment. Depending on sludge content and climate conditions for evaporation, sludge drying times may range from several days to weeks.

7.3.5.2 Plate-and-Frame Filter Press

The most widely used filter press is referred to as the plate-and-frame filter press. A filter press uses positive pressure provided by a mechanical device, such as a hydraulic ram, to drive water contained in the sludge through a filter medium. This type of unit comprises a series of recessed plates that are affixed with a filter medium (e.g., filter cloth) and are stacked together on a horizontal shaft. The plates form a series of spaces separated by the filter media and are otherwise sealed to withstand the internal pressures created during the filtration cycle. As the sludge is forced through the system, the water passes through the filter medium and is discharged through the filtrate port while the solids become trapped within the spaces, forming a dewatered cake against the filter medium.

When the cycle is over, the plates are separated, and the dewatered cake is released from the spaces into a collection bin. Removing the cake from the filter media is often performed manually by an operator. The filter press filtrate that results from the dewatering is usually piped back to the beginning of the treatment system. Figure 7-3 presents a diagram of a plate-and-frame filter press.

7.3.5.3 Rotary Vacuum Filter

A rotary vacuum filter consists of a cylindrical drum with a filter medium, such as cloth or wire mesh, around its perimeter. The drum is horizontally suspended within a vessel and is partially submerged in the sludge. The drum is rotated and the filter surface contacts the sludge within the vessel while a vacuum is drawn from within the drum. This draws the water through

the filter medium toward the axis of rotation and discharges it through a filtrate port. The solids become trapped against the filter medium, forming a dewatered cake around the outside of the drum. The dewatered cake is continuously scraped from the drum into a collection bin. Figure 7-4 presents a diagram of a rotary vacuum filter.

7.3.5.4 Centrifuge

Another method of sludge dewatering is centrifuging. Centrifuge designs are based on the principal of centrifugal force. To settle and separate higher density solids from wastewater, sludge is spun or rotated in the centrifuge, collected on the inner wall of the mechanism, and then scraped from the walls of the centrifuge. Certain wastewater treatment chemicals may be added to sludge in the centrifuge to bring additional pollutants out of solution and form an insoluble floc (e.g., as in chemical precipitation) that is also separated by the centrifugal forces.

7.3.6 Dissolved Air Flotation

Flotation is the process of influencing suspended particles to rise to the wastewater surface where they can be collected and removed. Dissolved air flotation is utilized by approximately 25% of TEC facilities in their treatment systems. During flotation, gas bubbles introduced into the wastewater attach themselves to suspended particles, thereby reducing their specific gravity and causing them to float. Flotation processes are utilized because they can remove suspended solids that have a specific gravity slightly greater than 1.0 more quickly than sedimentation.

Dissolved air flotation (DAF) is one of several flotation techniques used for wastewater treatment to extract free and dispersed oil and grease, suspended solids, and some dissolved pollutants from process wastewater. In DAF, two modes of operation may be employed to pressurize wastewater. In recycle pressurization, air is injected into a portion of recycled, clarified effluent and dissolved into a wastewater stream in an enclosed tank or pipe,

pressurizing the wastewater. In full flow pressurization, all of the influent wastewater is injected with air in a surge tank and is pumped to a retention tank under pressure to dissolve the air into the wastewater.

When the wastewater enters the flotation tank, the pressure is reduced, which causes fine air bubbles to be released. These bubbles make contact with the suspended particles via two separate mechanisms. The first mechanism involves the use of a flocculant, which causes rising air bubbles to be trapped inside flocculated masses as they increase in size. The second mechanism involves the intermolecular attraction between the solid particle and the air bubble, which causes the solid to adhere to the bubble. In either mechanism, the low density of the air bubble causes it to rise to the surface of the flotation tank with the flocculated or adhered solids attached.

DAF units are equipped with rakes that scrape the floc from the surface and into a sludge collection vessel, where it is subsequently pumped to a dewatering unit and later disposed. A sludge auger may be included in the DAF unit to remove solids that have settled to the bottom of the tank. Units are typically operated on a continuous basis and incorporate chemical mix tanks (if flocculants are used), flotation vessels, and sludge collection tanks in a single enclosed unit. Figure 7-5 presents a diagram of a DAF unit with pressurized recycle.

7.3.7 Coagulation/Flocculation

Coagulation and flocculation are processes that cause suspended solids in wastewater to coalesce. The coalesced particles tend to settle out of the wastewater more quickly than particles that have not undergone coagulation/flocculation. Approximately 24% of TEC facilities use coagulation/flocculation.

Coagulation consists of the addition and rapid mixing of a “coagulant,” the destabilization of colloidal and fine suspended solids, and the initial aggregation of those particles. Flocculation is the slow stirring to complete aggregation of those particles and form a floc which

will in turn settle by gravity (3). After rapid mixing, coagulant aids, such as polyelectrolytes, are often added to reduce the repulsive forces between the charged particles. Flocculation may also be accomplished by adding such materials as lime or sodium silicate to form loose agglomerates that carry the fine particles down with them. These settled solids form a sludge; therefore, coagulation/flocculation is typically followed by clarification to remove solids (see Section 7.3.9).

7.3.8 Filtration

Filtration is used to remove solids from wastewater by passing the wastewater through a material that retains the solids on, or within, itself. The percentage of TEC facilities that use filtration (excluding membrane filtration, which is discussed separately in Section 7.3.15) is 24 percent. A wide variety of filter types are used by the TECI including media filters (e.g., sand, gravel, charcoal), bag filters, and cartridge filters. A filter press (see Section 7.3.5) may be used for in-line wastewater filtration. The flow pattern of filters is usually top-to-bottom; however, upflow filters, horizontal filters, and biflow filters are also used.

The complete filtration process typically involves two phases: filtration and backwashing. As the filter becomes saturated with trapped solids, the efficiency of the filtration process decreases. As the head loss across the filter bed (i.e., measure of solids trapped in the filter) increases to a limiting value, the end of the filter run is reached, and the filter must be backwashed to remove the suspended solids in the bed. During backwashing, the flow through the filter is reversed so that the solids trapped in the media are dislodged and can exit the filter. The bed may also be agitated with air in order to aid in solids removal. The backwash water is then recycled back into the wastewater feed stream.

The type of filter used depends on various factors such as the operating cycle (i.e., whether the wastewater is being filtered continuously or in batches) or the nature of the solids passing through the filter. The filter type can also be determined by the filtration mechanism (i.e., whether the filtered solids are stopped at the surface of the medium and accumulate to form a filter cake or are trapped within the pores or body of the filter).

7.3.9 Clarification

Clarification involves holding wastewater in a quiescent state so that contaminants can separate by density. Clarification uses the same principles for treatment as gravity settling but differs from gravity settling in that it is typically used after coagulation/flocculation and/or biological treatment. Approximately 23% of the TECI use clarification in their wastewater treatment systems.

Clarifiers consist of settling tanks and are commonly equipped with a sludge scraper mounted on the floor of the clarifier to rake sludge into a sump for removal. The bottom of the clarifier may also be sloped to facilitate sludge removal. Clarification can be used as either a pre-or post-treatment step for various operations to aid in removing settleable solids, free oil and grease, and other floating material. Clarifiers are often referred to as primary or secondary sedimentation tanks. Primary clarification is used to remove settleable solids from raw wastewater or wastewater treated by coagulation/flocculation. Secondary clarification is normally used in activated sludge systems to remove biomass. A portion of the sludge biomass is often recycled from the secondary clarifier back to the activated sludge biological oxidation unit (see Section 7.3.10). Secondary clarification may include the addition of chemicals to aid in the coagulation and agglomeration of suspended solids following biological treatment. Polymers are typically used as coagulant aids, but other coagulants (e.g., alum) may also be used. Figure 7-6 presents a diagram of a clarifier.

7.3.10 Biological Oxidation

Biological oxidation is a reaction caused by biological activity which results in a chemical combination of oxygen with organic matter to yield relatively stable end products such as carbon dioxide and water (3). Approximately 9% of the TECI uses biological oxidation to treat wastewater. In wastewater treatment, this is most commonly accomplished with an activated sludge treatment system, but aerated lagoons, trickling filters, and rotating biological contactors (RBCs) can also be used to perform biological oxidation of wastewater.

An activated sludge treatment system normally consists of an aeration basin, a secondary clarifier, and a sludge recycle line. Equalization of flow, pH, temperature, and pollutant loading is necessary to obtain consistent, adequate treatment. A settling tank may be used to remove settleable solids prior to aeration. An aerobic bacterial population is maintained in the aeration basin where oxygen, recycled sludge, and nutrients (usually nitrogen and phosphorus) are added to the system. Prior to the aeration basin, oxygen may also be added to wastewater in preaeration tanks. Oxygen is normally supplied by aerators that also provide mixing to help keep microorganisms in suspension. The activated sludge-wastewater mixture, or “mixed liquor,” is then sent to a secondary clarifier that controls the amount of suspended solids discharged and provides recycled sludge back to the aeration basin to keep an optimal concentration of acclimated microorganisms in suspension.

Sludge produced by these systems generally consists of biological waste products and expired microorganisms and is typically discharged from the clarifier. However, under certain operating conditions, this sludge may accumulate in the aeration basin and may require periodic removal. Figure 7-7 presents a diagram of an activated sludge system.

7.3.11 Chemical Precipitation/Separation

Chemical precipitation/separation is a process that renders dissolved pollutants insoluble and uses the resulting phase differential to separate pollutants from wastewater. Approximately 6% of TEC facilities use chemical precipitation/separation. During chemical precipitation processes typical in the TECI, insoluble solid precipitates are formed from the organic or inorganic compounds in the wastewater through the addition of chemicals and/or pH adjustment. Sedimentation or filtration then separates out the solids from the wastewater. Chemical precipitation is generally carried out in four phases:

1. Addition of the chemical to the wastewater;
2. Rapid (flash) mixing to homogeneously distribute the chemical;
3. Slow mixing to promote particle growth by flocculation; and
4. Sedimentation or filtration to remove the flocculated solid particles.

Chemical precipitation systems normally consist of a rapid mixer, a chemical feed system to add the precipitation agent, a flocculation tank, and a sedimentation tank. In batch chemical precipitation systems, the treated wastewater is held in the unit long enough to allow the solids to settle out. The water is then pumped from the unit, and the resulting sludge is removed for further dewatering and subsequent disposal.

Precipitation agents, such as polyaluminum chloride, ferric chloride, and lime, work by reacting with pollutant cations (e.g., metals) and some anions to convert them into an insoluble form for subsequent removal by gravity settling. The pH of the wastewater also affects how much pollutant mass is precipitated, as pollutants precipitate more efficiently in different pH ranges. Figure 7-8 presents a diagram of a batch chemical precipitation unit.

7.3.12 Grit Removal

Grit removal is the process of eliminating heavy, suspended material from wastewater. Grit removal is only used by 4% of TEC facilities. Grit removal differs from gravity settling/clarification in that it is typically performed in a smaller tank and has a shorter retention time. Removal is accomplished using a settling chamber and a collection mechanism, such as a rake. Grit chambers may also be aerated to remove floatable solids. This unit operation is performed to prevent excess wear on pumps, accumulations in aeration tanks and clarifiers, and clogging of sludge piping (3).

7.3.13 Chemical Oxidation

Chemical oxidation is used in wastewater treatment to destroy priority pollutants or other organic pollutants by oxidizing them with an oxidizing agent. Approximately 2% of TEC facilities use chemical oxidation. Chemical oxidation systems consist of a tank, a mixer, and a chemical feed system to add the oxidizing agent. During the chemical oxidation reaction, one or more electrons are transferred from the oxidizing chemical (electron donor) to the targeted pollutants (electron acceptor), causing their destruction. An oxidant often used by the TECI is

hydrogen peroxide. Other oxidants used in industry include chlorine, ozone, and potassium permanganate.

7.3.14 Activated Carbon Adsorption

Activated carbon removes organic constituents from wastewater by physical and chemical forces that bind the constituents to the carbon surface and internal pores. Activated carbon adsorption is widely used in the treatment of industrial wastewaters because it adsorbs an extensive variety of organic compounds. However, less than 1% of TEC facilities currently use activated carbon adsorption. The term “activated carbon” refers to carbon materials, such as coal or wood, that are processed through dehydration, carbonization, and oxidation to yield a material that is highly adsorbent due to a large surface area and a high number of internal pores per unit of mass. In general, organic constituents possessing certain properties (e.g., low water solubility and high molecular weight) and certain chemical structures (e.g., aromatic functional groups) are amenable to treatment by activated carbon adsorption.

An activated carbon adsorption system usually consists of a column of bed containing the activated carbon. The most common form of activated carbon for wastewater treatment is granular. Powdered activated carbon is used less frequently for wastewater treatment due to the difficulty of regeneration, reactor system design considerations, and its tendency to plug more easily than granular activated carbon, although it may be used in conjunction with biological treatment systems.

The carbon adsorption capacity (i.e., the mass of the contaminant adsorbed per mass of carbon) for specific organic contaminants is related in part to the characteristics of each compound. Competitive adsorption of mixed compounds has a major effect on adsorption (i.e., the carbon may begin preferentially adsorbing one compound over another compound and may even begin desorbing the other compound). Process conditions, process design factors, and carbon characteristics also affect adsorption capacity.

When the adsorption capacity of the carbon is exhausted, the spent carbon is either disposed or regenerated; the choice is generally determined by cost. Carbon may be regenerated by removing the adsorbed organic compounds from the carbon through steam regeneration, thermal regeneration, or physical/chemical regeneration. The most common methods to regenerate carbon used for wastewater treatment are thermal and steam regeneration. These methods volatilize the organic compounds that were adsorbed onto the carbon. Afterburners are required to ensure destruction of the organic vapors. A scrubber may also be necessary to remove particulates from the air stream. Physical/chemical regeneration uses a solvent, which can be a water solution, to remove the organic compounds.

7.3.15 Membrane Filtration

Membrane filtration is a term applied to a group of processes that use a pressure-driven, semipermeable membrane to separate suspended, colloidal, and dissolved solutes from a process wastewater. Less than 1% of TEC facilities use membrane filtration. During operation, the feed solution flows across the surface of the membrane. “Clean” water permeates the membrane by passing through pores in the membrane, leaving the contaminants and a portion of the feed behind. The clean or treated water is referred to as the permeate or product water stream, while the stream containing the contaminants is called the concentrate, brine, or reject stream. The size of the pores in the membrane is selected based on the type of contaminant to be removed. The pore size will be relatively large for the removal of precipitates or suspended materials, or very small for the removal of inorganic salts or organic molecules. Figure 7-9 presents a diagram of membrane filtration unit.

For industrial applications, the product water stream will either be discharged or, more likely, recycled or reused. The reject stream is normally disposed, but if the reject is of suitable quality, it can also be recycled or reused. Types of membrane filtration systems available include microfiltration, ultrafiltration (UF), and reverse osmosis (RO). The applicability of each of these membrane filtration technologies to the TECI is discussed below.

7.3.15.1 Microfiltration

Microfilters are generally capable of removing suspended solids and colloidal matter with diameters of greater than 0.1 microns and are commonly made from woven polyester or ceramic materials. The systems can be operated at feed pressures of less than 50 pounds per square inch gauge (psig). The feed stream does not require extensive pretreatment, and the membrane is relatively resistant to fouling and easily cleaned. Microfilters are capable of recovering up to 95% of the feed stream as product water.

7.3.15.2 Ultrafiltration

Ultrafiltration is similar to microfiltration except that a UF membrane has smaller pores. The “tightest” UF membrane is typically capable of rejecting molecules having diameters of greater than 0.001 microns. The system operates at a feed pressure of 50 to 200 psig. UF systems are capable of recovering from 90 to 95% of the feed as product water.

7.3.15.3 Reverse Osmosis

Reverse osmosis systems differ from microfiltration and ultrafiltration systems in that they have the ability to reject dissolved organic and inorganic molecules. RO systems are generally capable of removing particles with diameters less than 0.001 microns. RO membranes are commonly made from cellulose acetate; however, polysulfone, polyamide, or other polymeric materials may also be used. Reverse osmosis systems can be operated at feed pressures of 250 to 600 psig. RO membranes are very susceptible to fouling and may require extensive pretreatment of wastewater to remove wastewater constituents that can cause fouling. Oxidants (which may attack the membrane), particulates, oil, grease, and other materials that could cause a film or scale to form, plugging the membrane, must be removed by pretreatment. Reverse osmosis systems are capable of recovering up to 50 to 90% of the feed stream as product water. The dissolved solids concentration in the feed determines the percent recovery that can be obtained as well as the required feed pressure to operate the system.

7.4 **References**¹

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2. Viessman, Warren, Jr. and Mark J. Hammer. Water Supply and Pollution Control, Fifth Edition. Harper Collins College Publishers. New York, NY, 1993.
3. Reynolds, Tom and Paul Richards. Unit Operations and Processes in Environmental Engineering. PWS Publishing. Boston, MA, 1996.

¹For those references included in the administrative record supporting the TECI rulemaking, the document control number (DCN) is included in parentheses at the end of the reference.

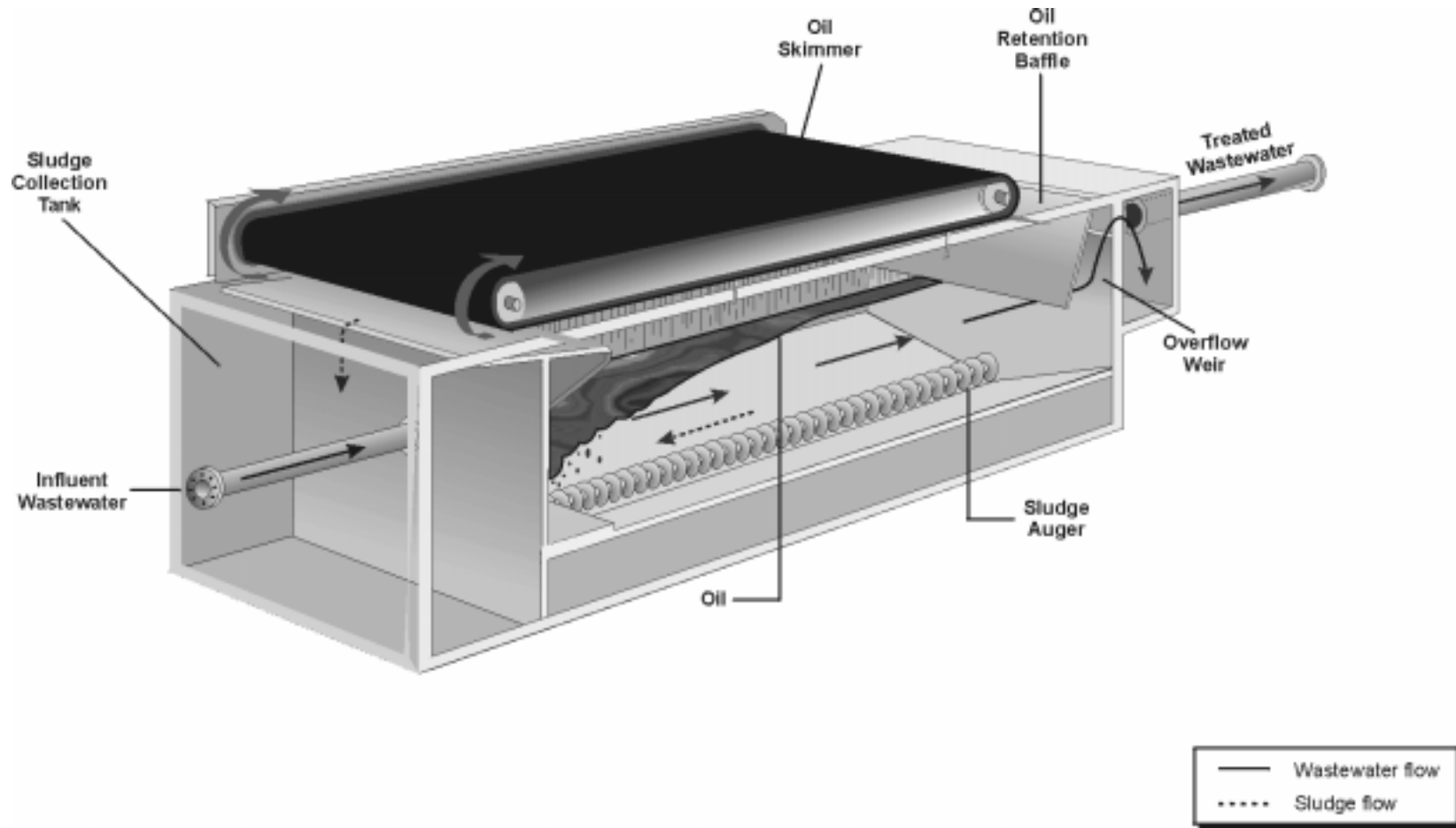


Figure 7-1. API Oil/Water Separator

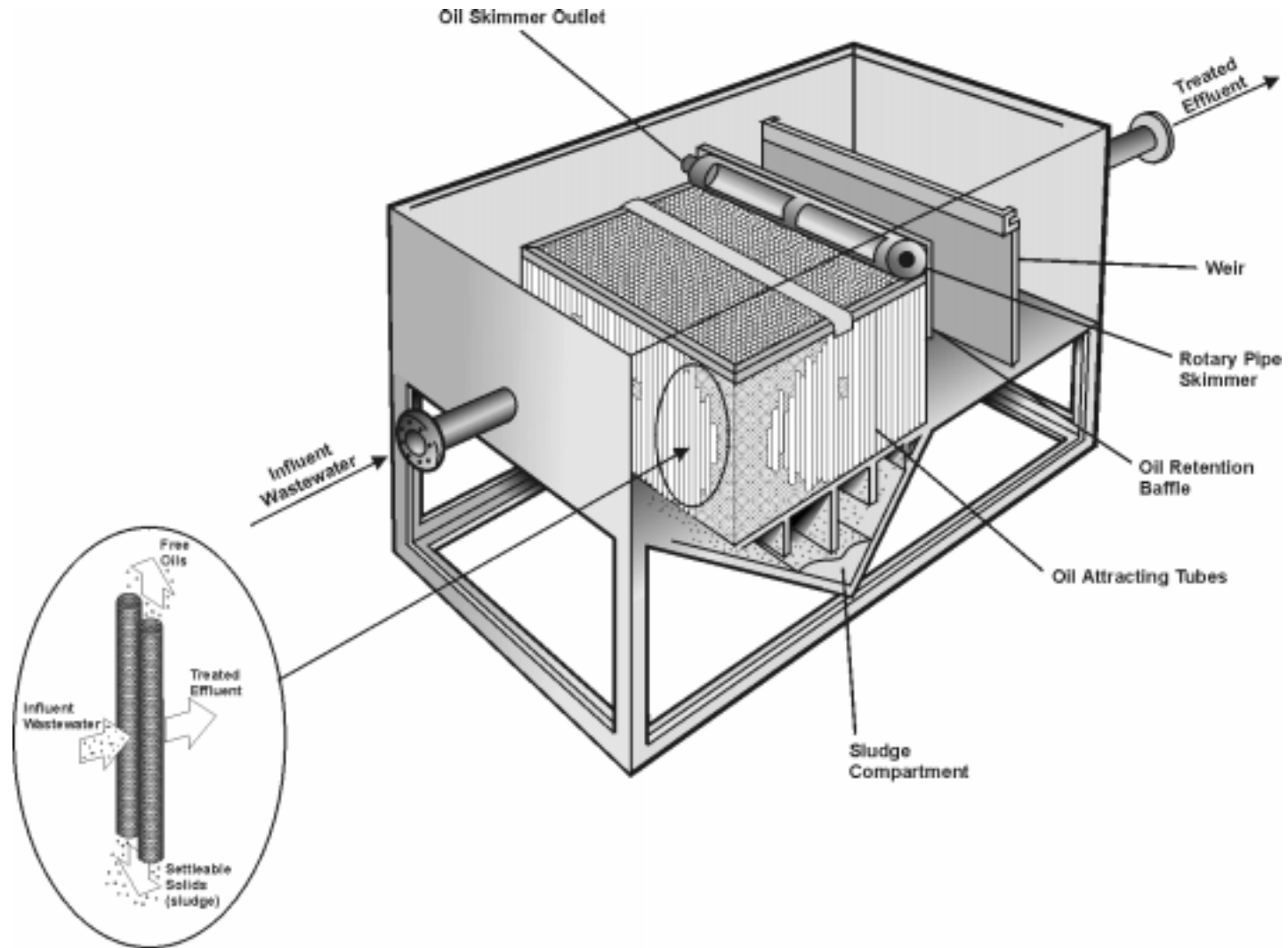


Figure 7-2. Coalescing Oil/Water Separator

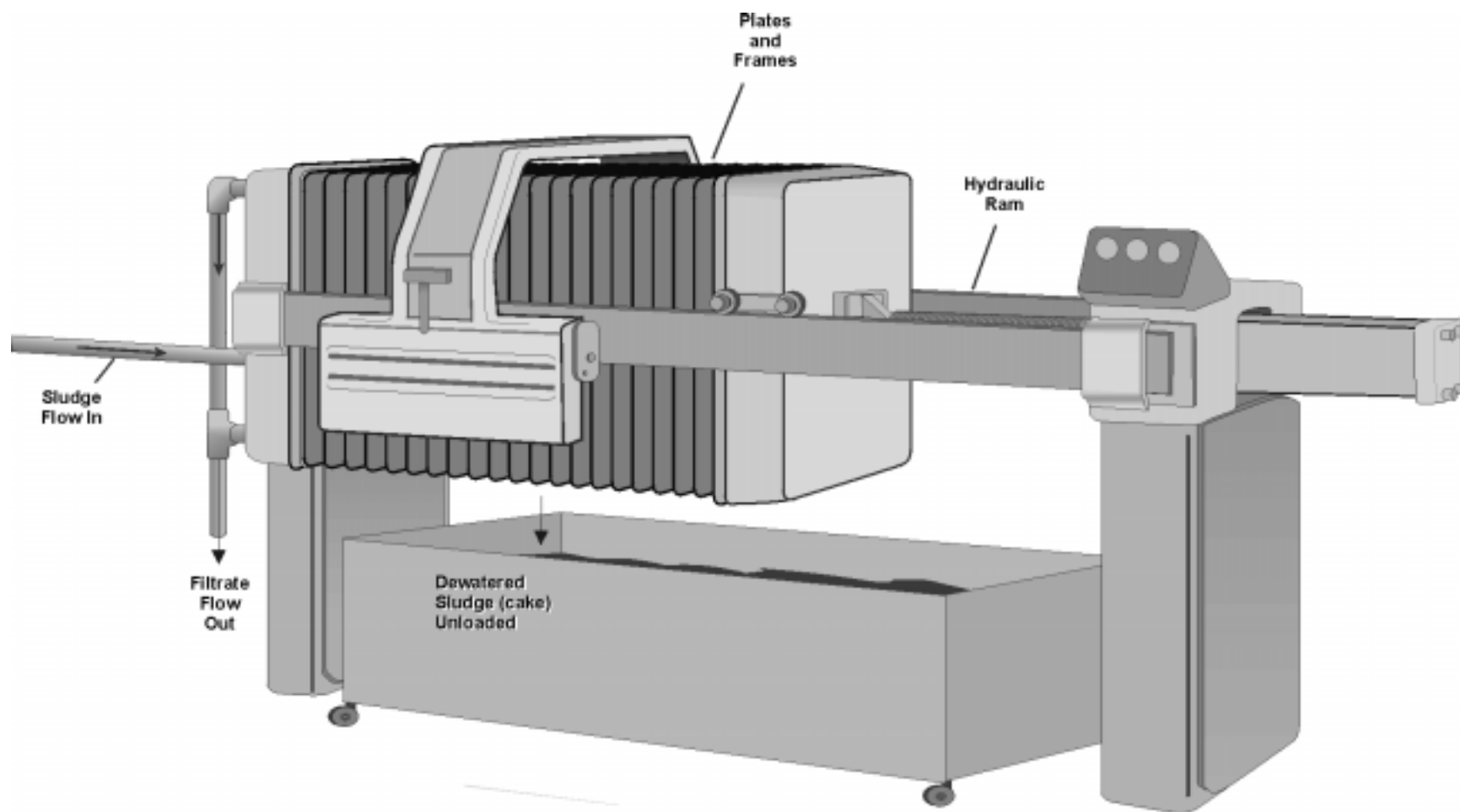


Figure 7-3. Plate-and-Frame Filter Press

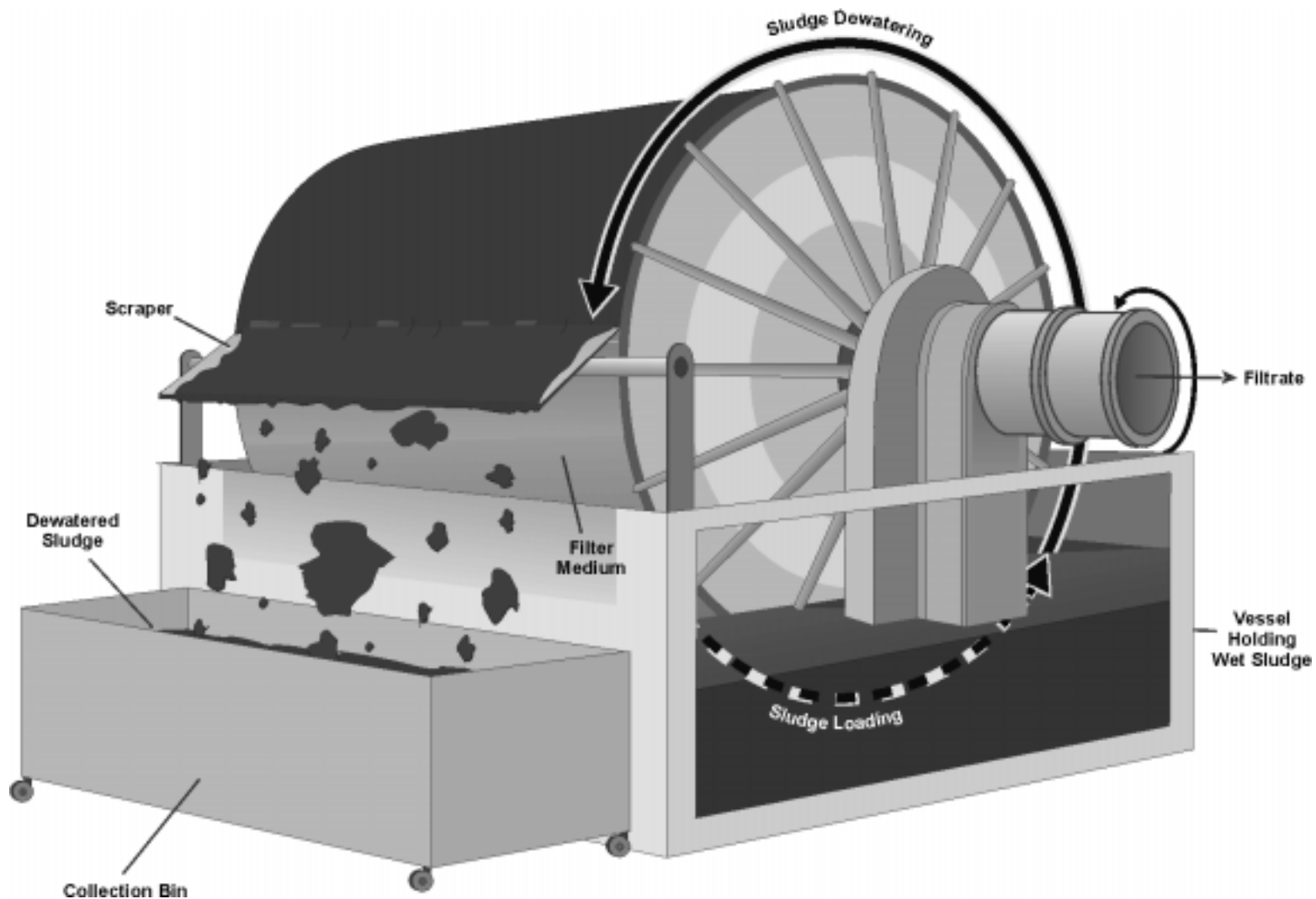


Figure 7-4. Rotary Vacuum Filter

7-31

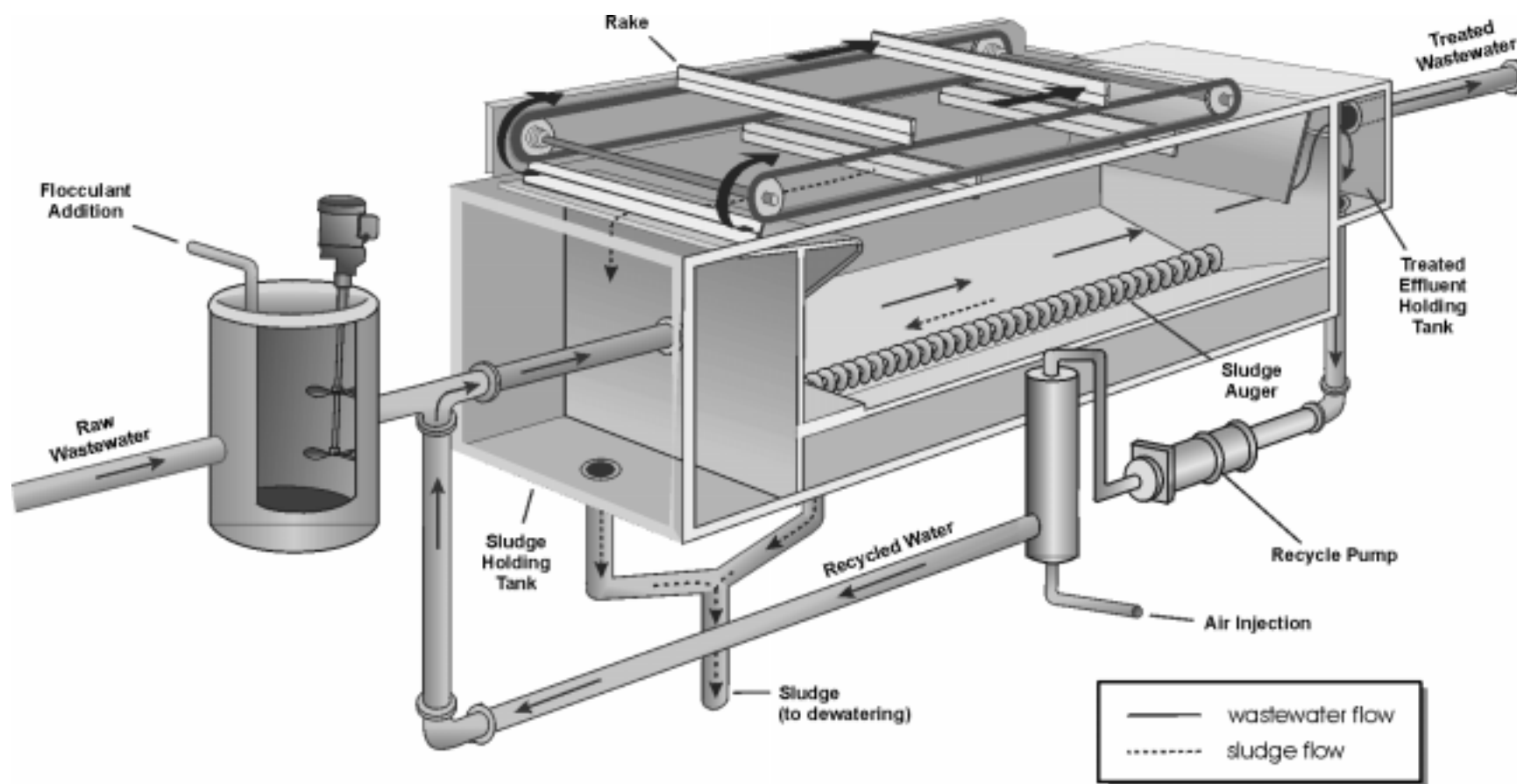


Figure 7-5. Dissolved Air Flotation Unit with Pressurized Recycle

7-32

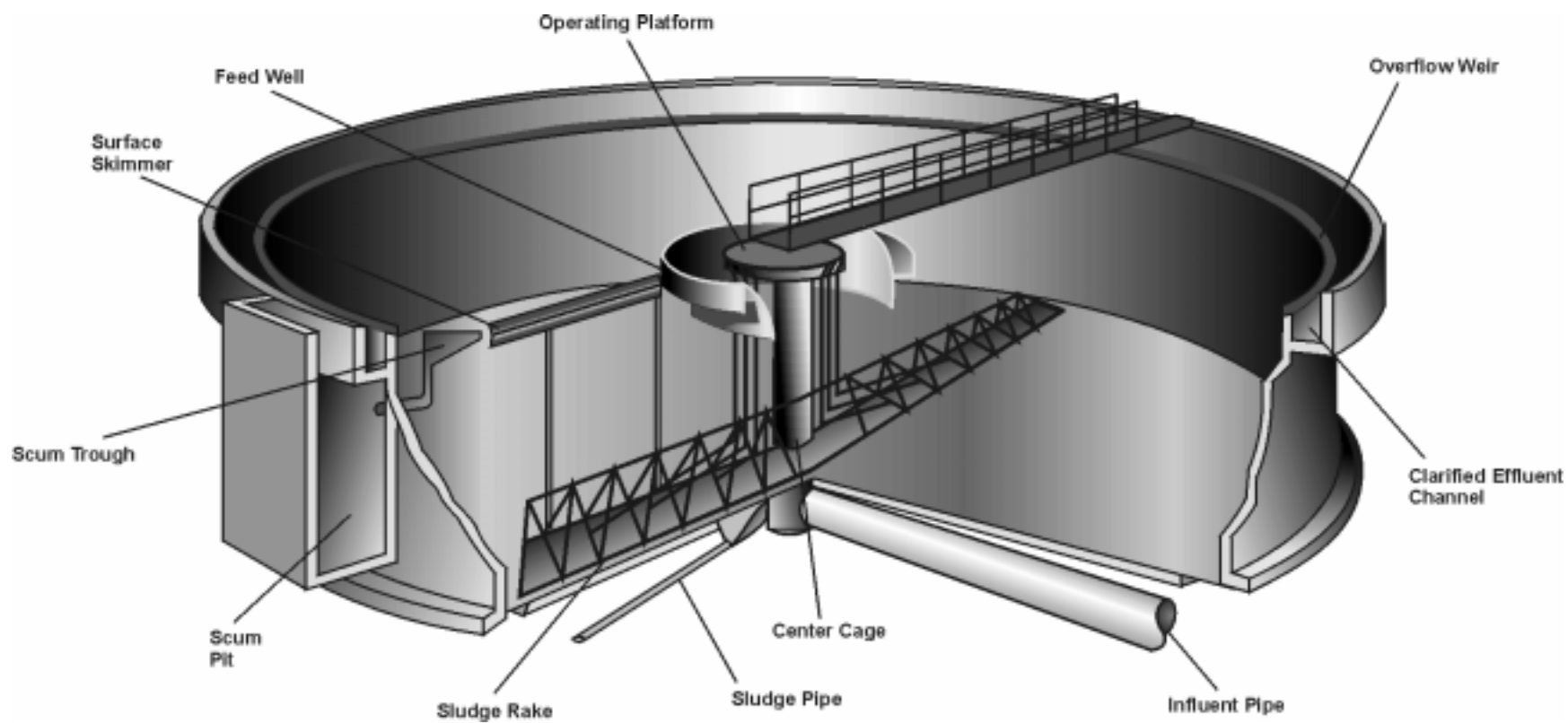


Figure 7-6. Clarifier

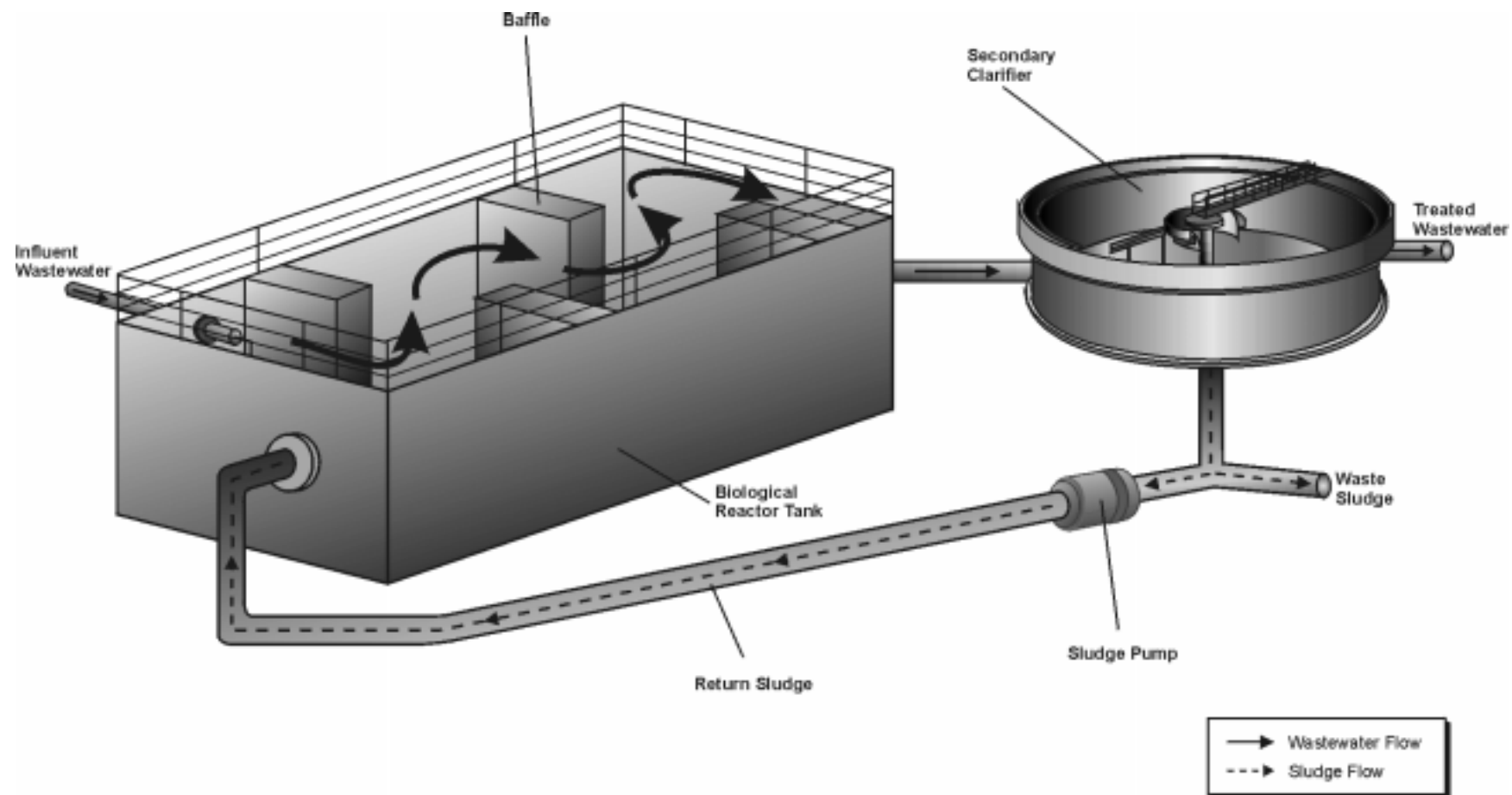


Figure 7-7. Activated Sludge System

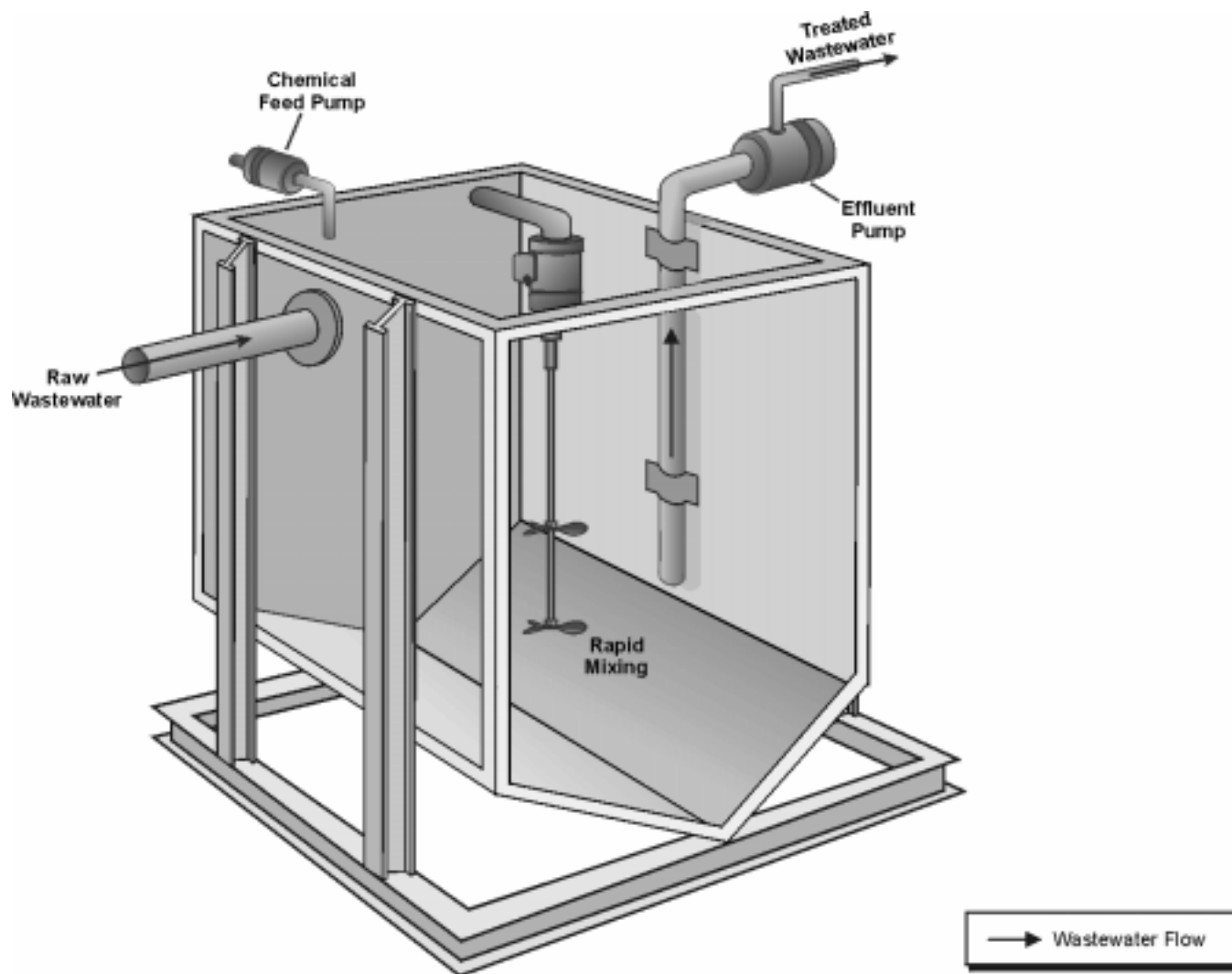


Figure 7-8. Batch Chemical Precipitation Unit

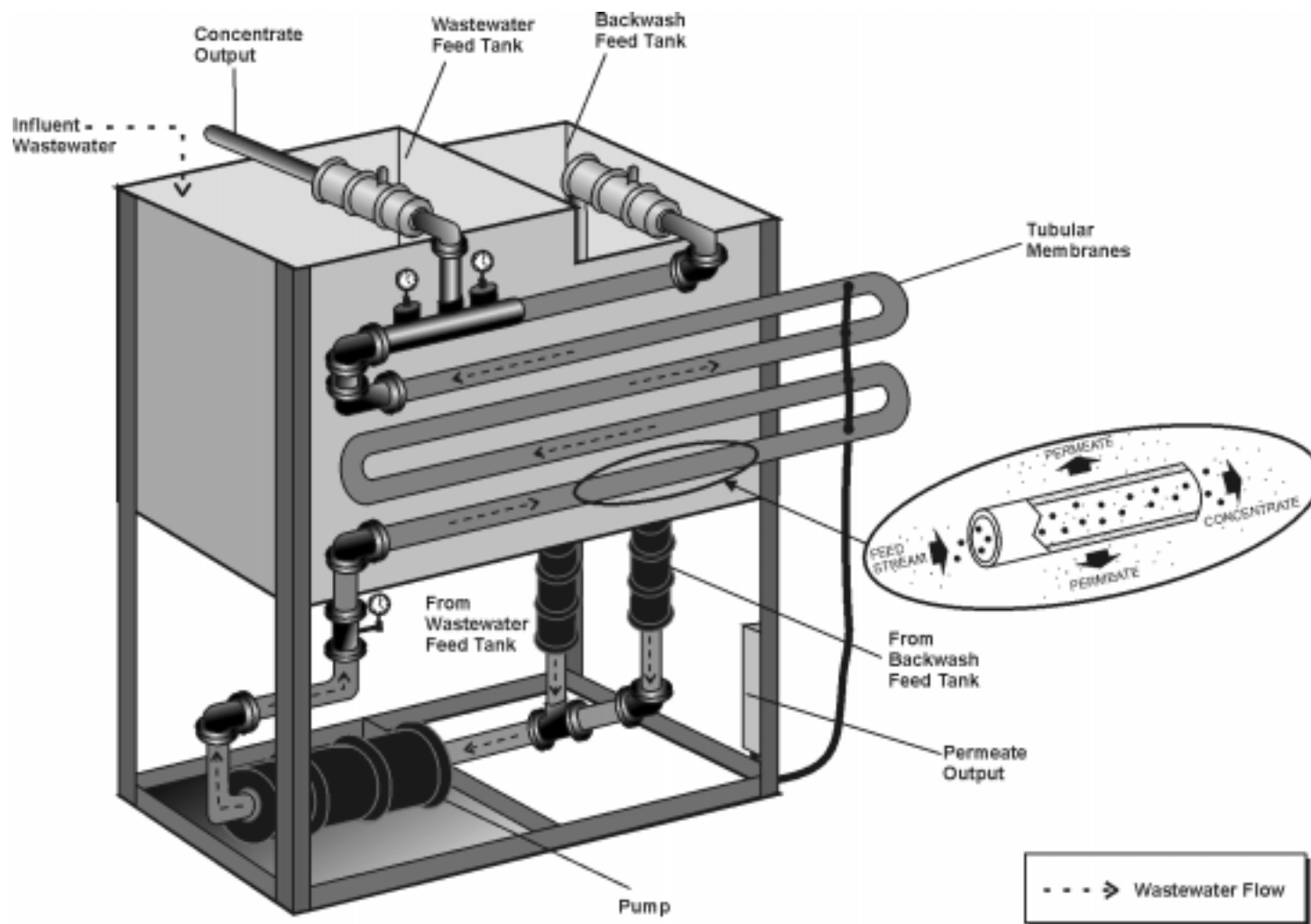


Figure 7-9. Membrane Filtration Unit